Comparison of 3D-Localization of Virtual Sound Sources between Normal-Hearing and Cochlear-Implant Listeners

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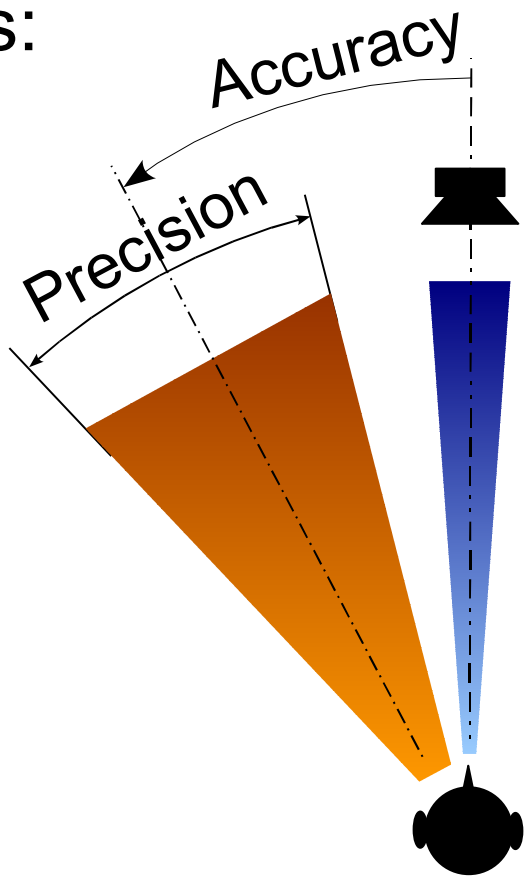
Main Questions

- Ability to localize sound sources:
  - Polar:
    - Accuracy
    - Precision
    - Front / Back Confusions
  - Lateral:
    - Expect worse precision than NHs
    - Already studied by others
- Comparison between
  - NH and CI listeners
- Effects of training



3D-Sound Localization: NH vs. CI

	NH	CI
Frequency range:	up to 20 kHz	up to 8 kHz
Number of channels:	~3500 hair cells	up to 22 electrodes
Frequency resolution:	critical bandwidth	spread of excitation
Compression:	cochlear compression	amplitude mapping
Place of signal acquisition:	ear drum / ear canal entrance	behind the ear microphone

HRTF Measurements

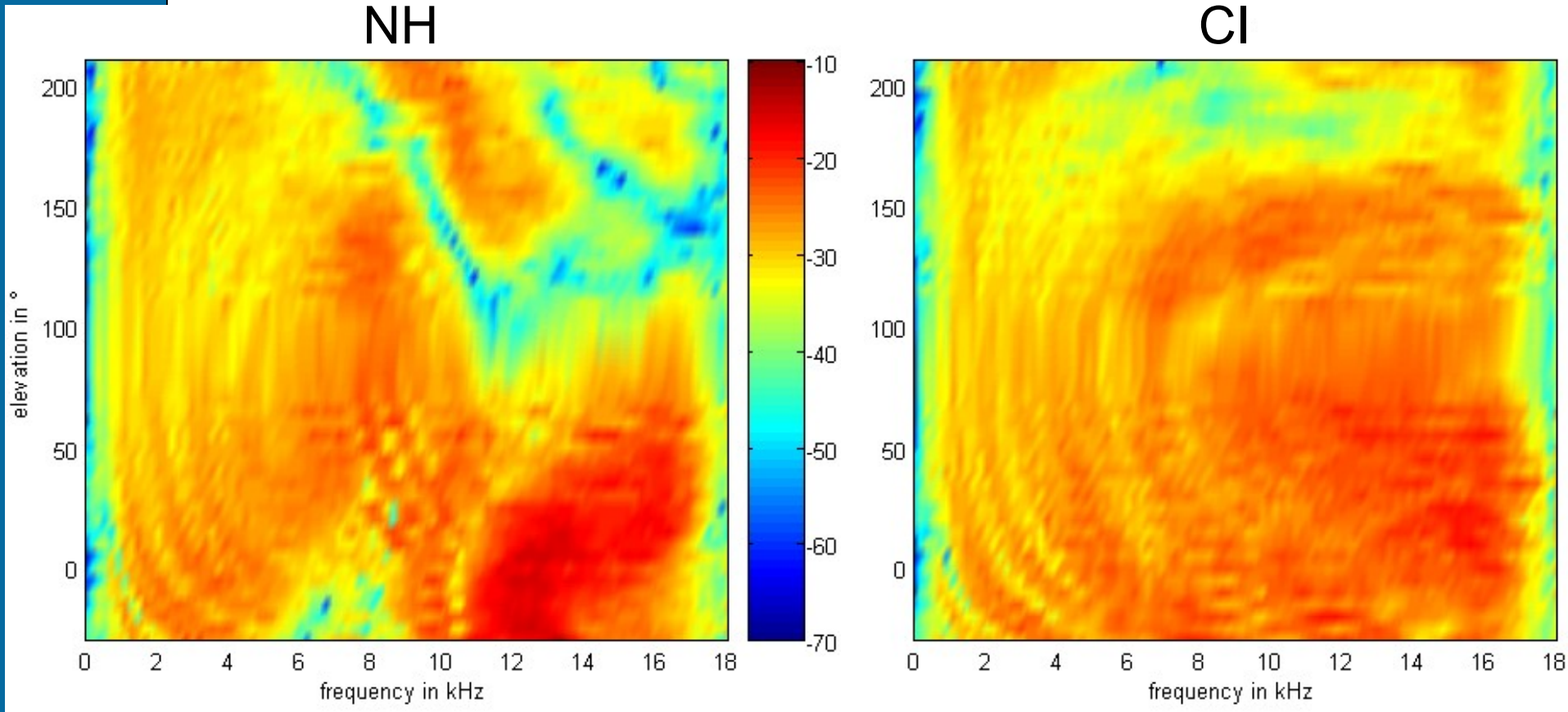
- System identification method:
  - Multiple Exponential Sweep Method (Majdak et al. 2008)
  - NHs: entrance of the blocked-ear canal
  - CIs: mic-output of a behind-the-ear processor

HRTF Measurements

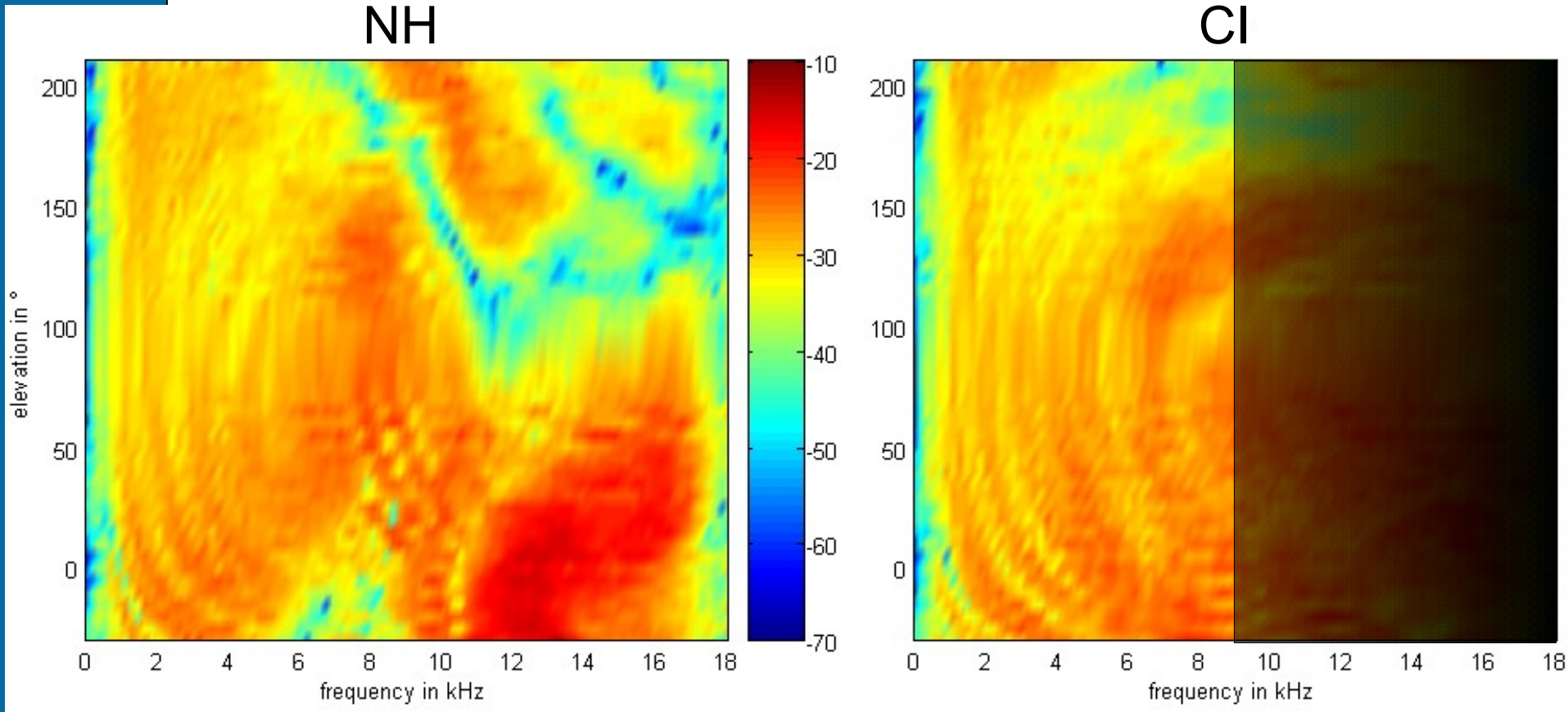
- Positions:
  - 1550 positions in total
    - Horizontal plane: 360°-range in 2.5° steps
    - Vertical plane: -30° to +80° in 5° steps
  - Subject's position controlled (± 2.5 cm; ± 2.5°)
- Directional Transfer Functions (DTF)
  - Equipment equalization
  - Removing of the common transfer function

    (Diffuse-field equalization)
  - FIR-Filters with the length of 5.3 ms (256 taps)

Comparison of DTFs for the median plane

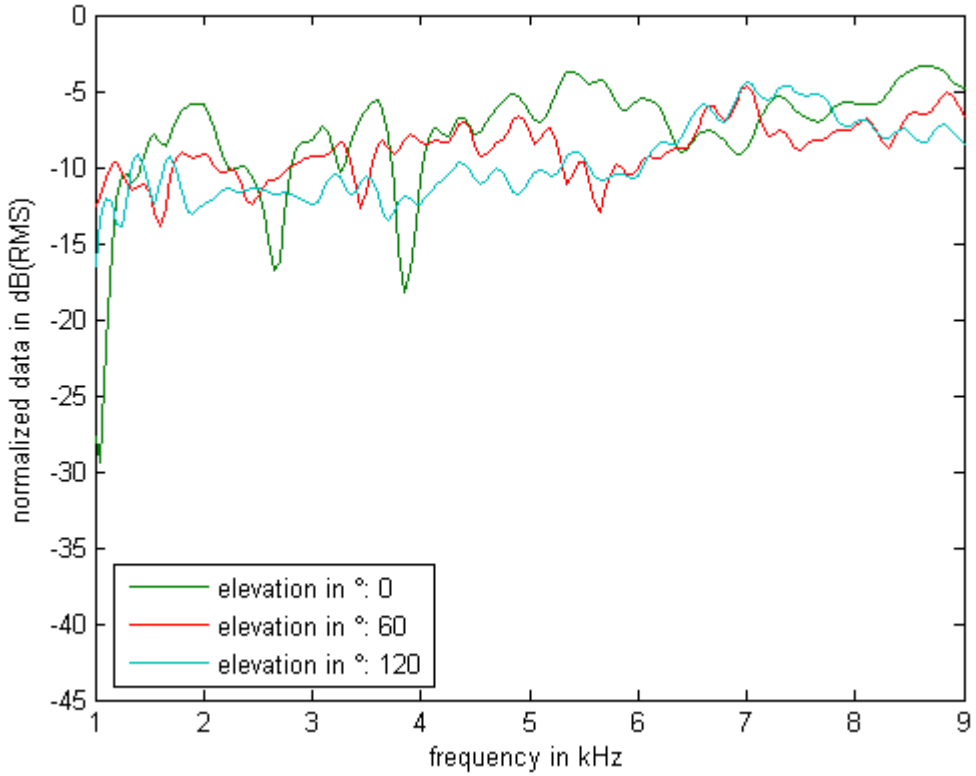


Comparison of DTFs for the median plane

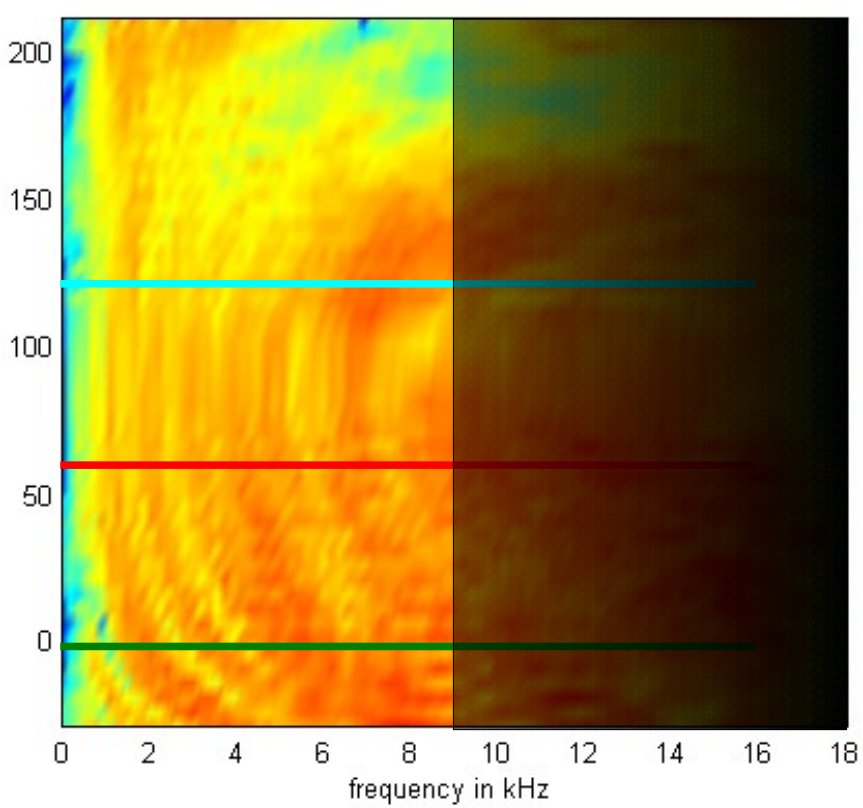


Comparison of DTFs for the median plane

CI



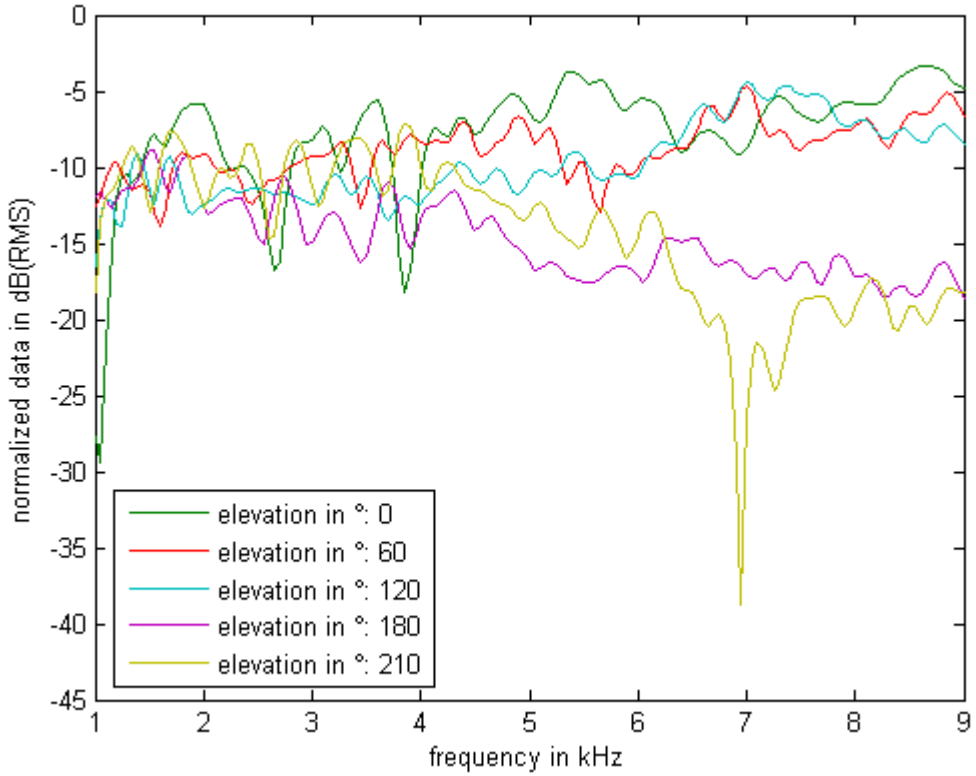
CI



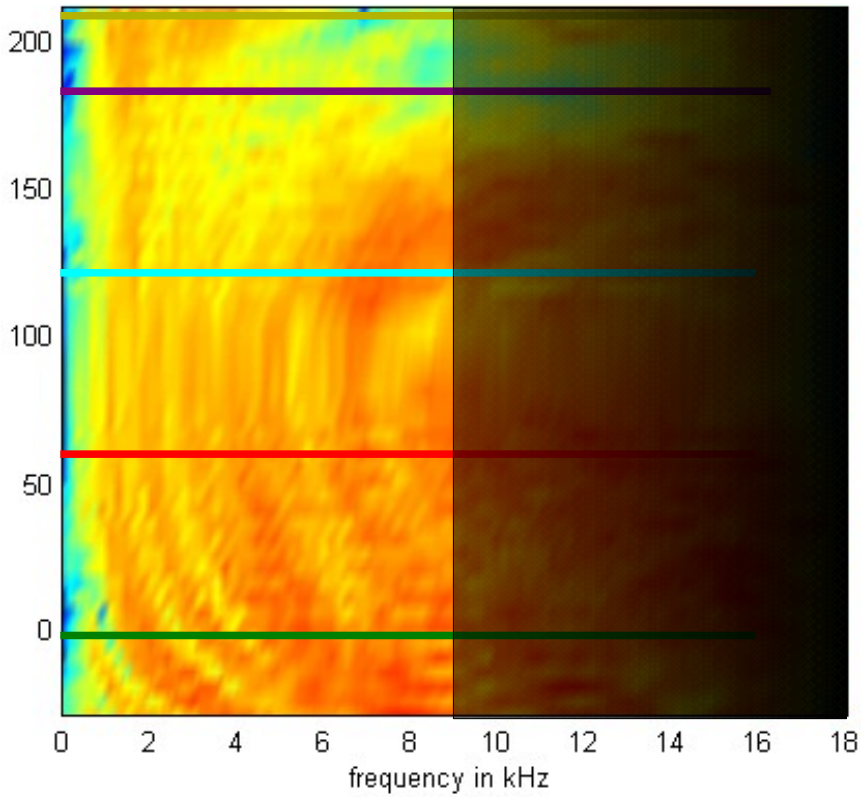
- Small differences for local elevation changes

Comparison of DTFs for the median plane

CI



CI



- Small differences for local elevation changes
- Larger differences for different quadrants

Stimuli

- Virtual acoustic stimuli (VAS):
  - Gaussian white noise, duration of 500 ms
  - Presented via
    - Headphones (NH)
    - Line input of the processors (CI)
  - Sensation level of 50 dB
  - Level roving in the range of 5 dB (trial-to-trial)
- Tests in a dark sound chamber
  - (A-weighted SPL of the background noise: 18 dB)

Apparatus and Subjects

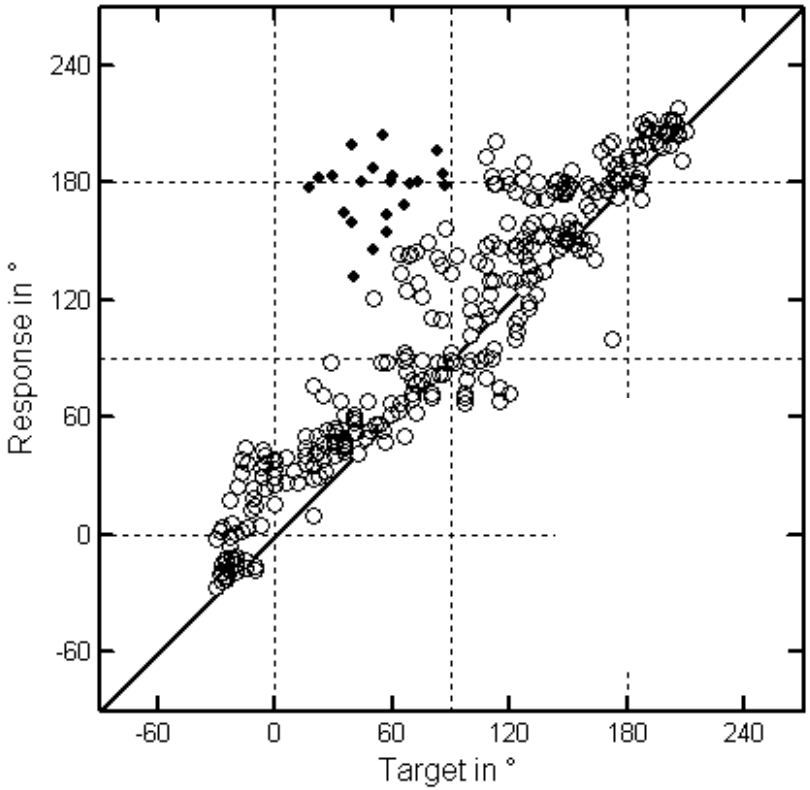
- Virtual Visual Environment (VE)
  - Presented via head mounted display (HMD):
    - Stereoscopic view, in color, **without depth**
    - Field of View: 32° x 24° (hor. x vert.)
  - Subject's position and orientation:
    - Tracked in real-time
    - Azimuth and elevation for the head (no movements)
  - Manual pointer as response
- Subjects:
  - 4 **naïve** NH listeners (no auditory deficits)
  - 4 **naïve** bilateral CI listeners (CIS+ [MED-EL] users)

Procedure

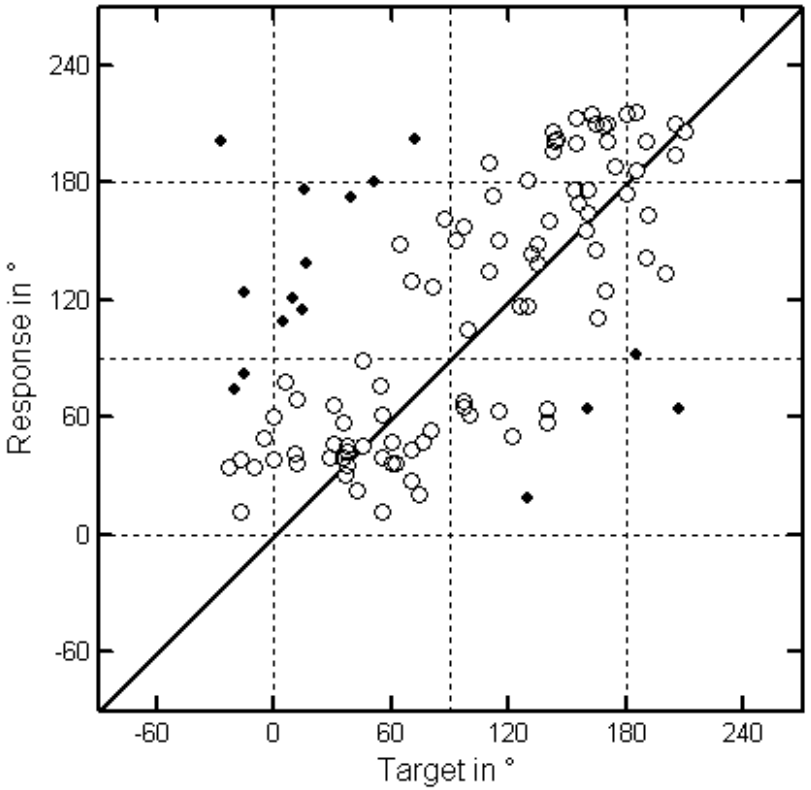
- Targets:
  - 400 random positions per condition (out of possible 1550)
  - Elevation: -30° to 80°, Azimuth: 360° range
  - Test in blocks
- Procedure:
  - Procedural Training (until response error < 2°)
  - Localization Test (no feedback, 100 trials per block)
  - Localization Training (visually guided associative training, 50 trials per block)

Polar Results - Naïve Subjects

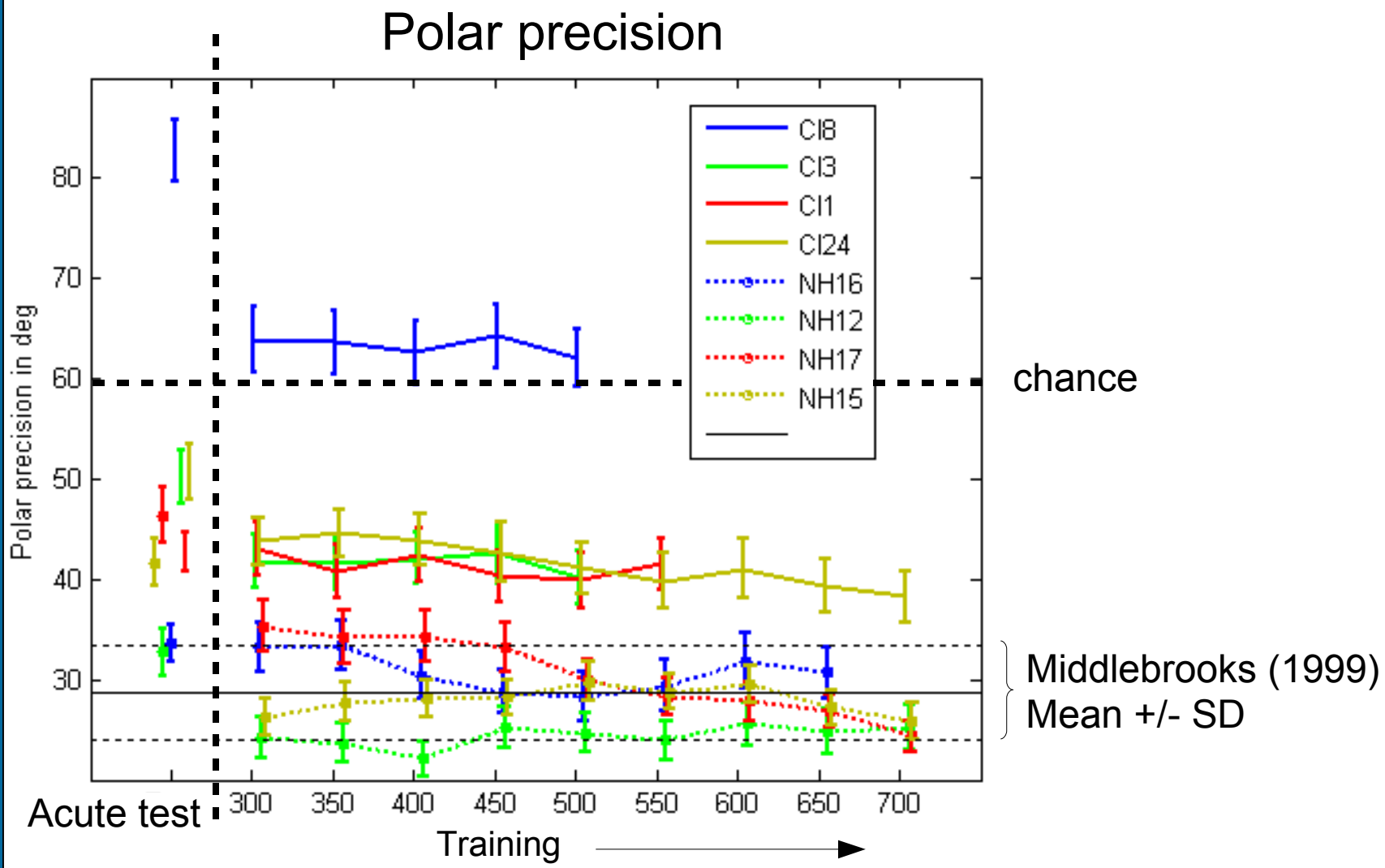
NH



CI



Polar Results – Training Progress



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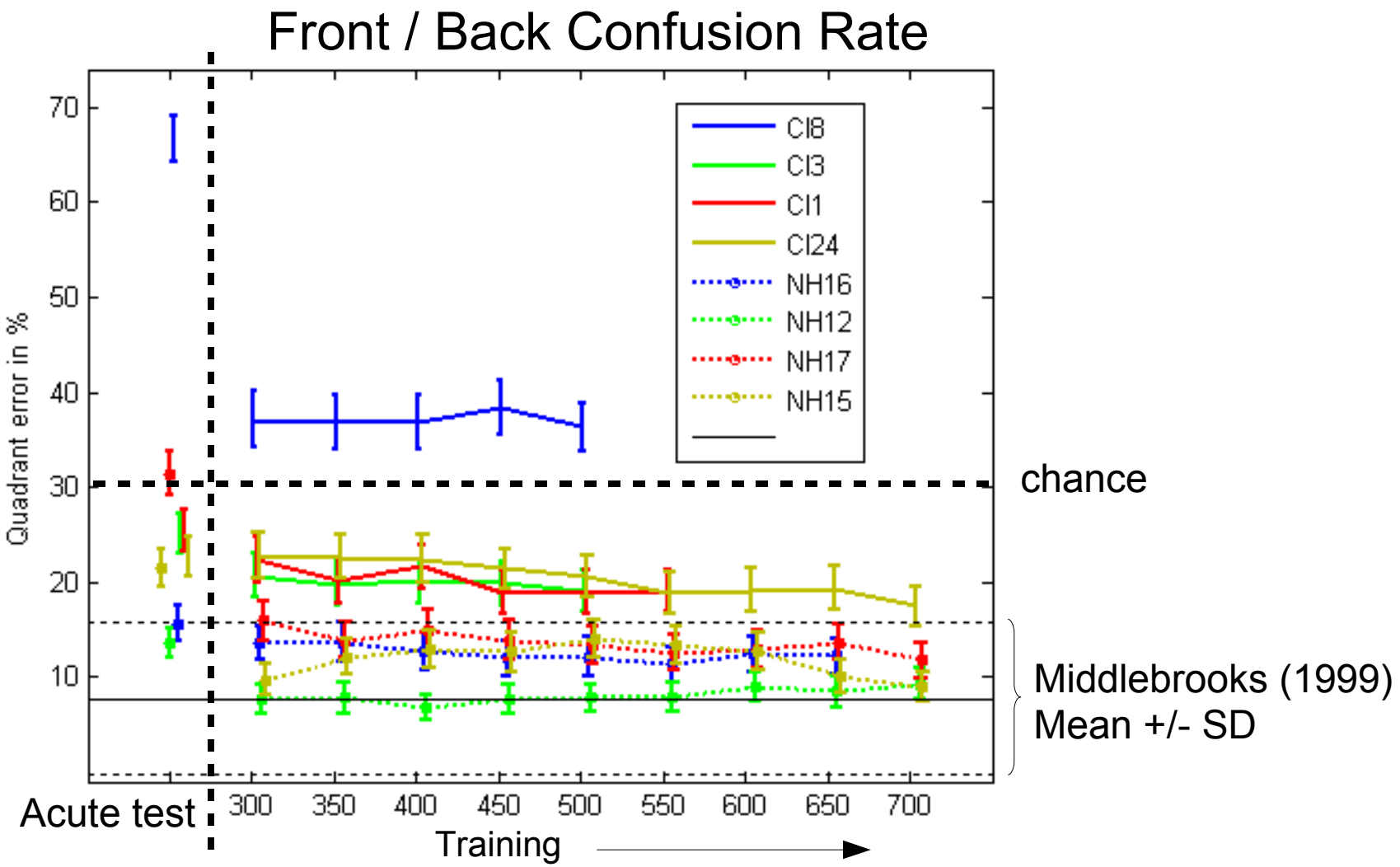
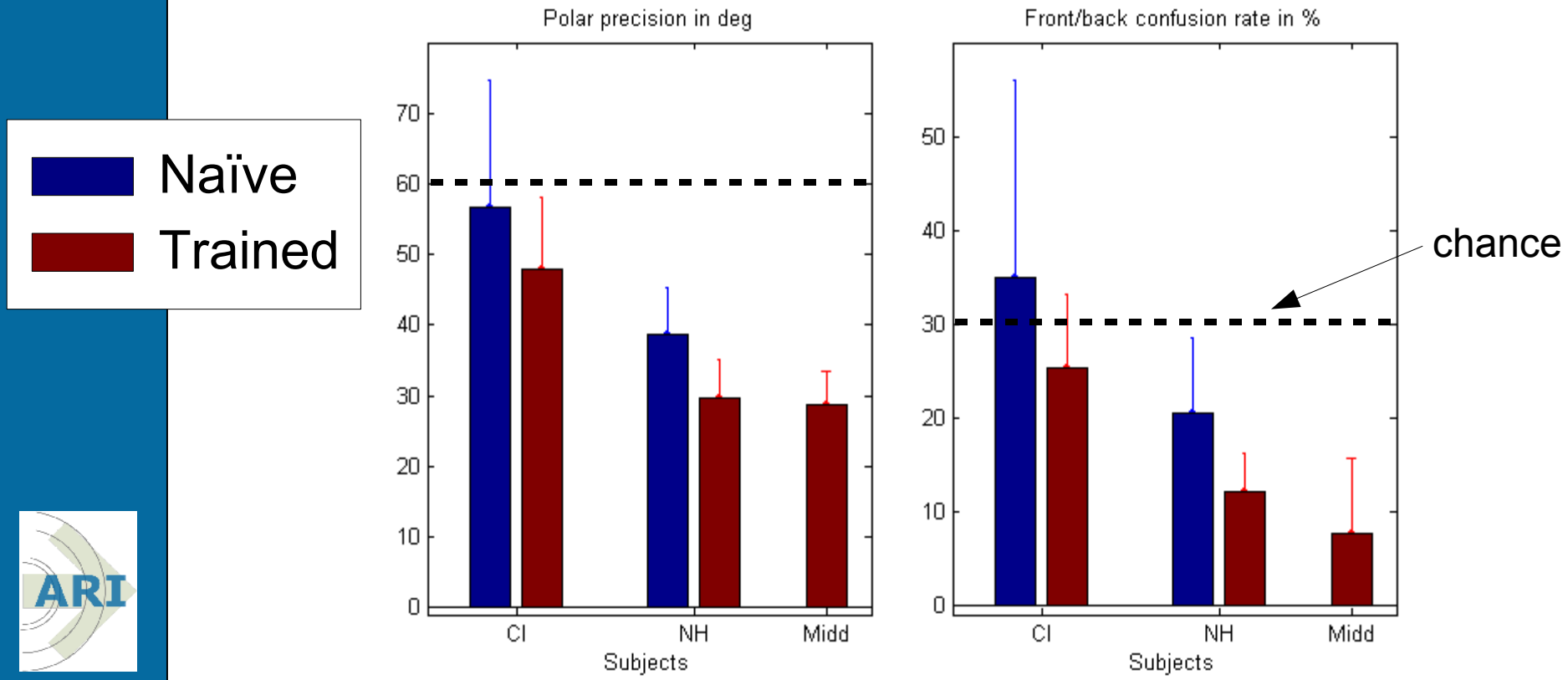


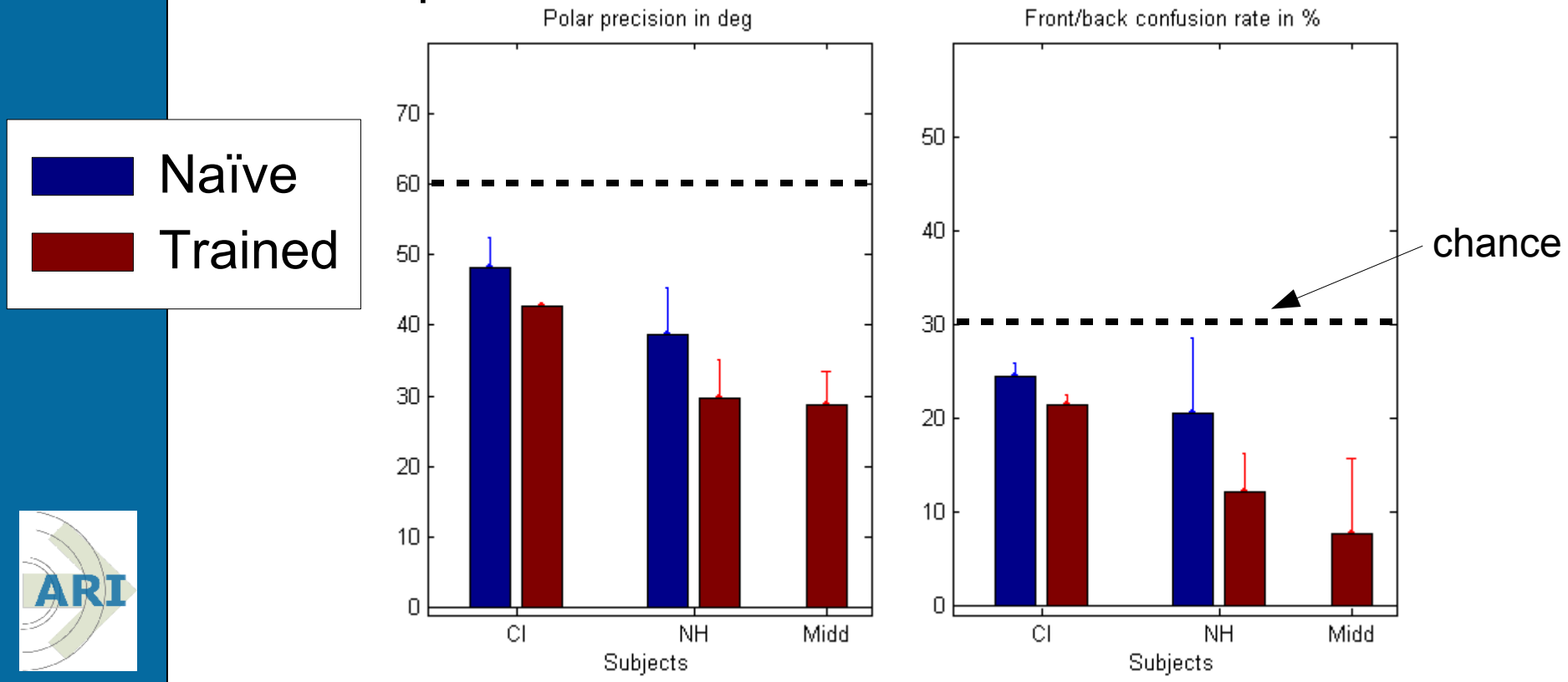
Polar Results – Group Data

- Polar:
  - CIs worse than NHs and...
  - ... **not** better than chance?



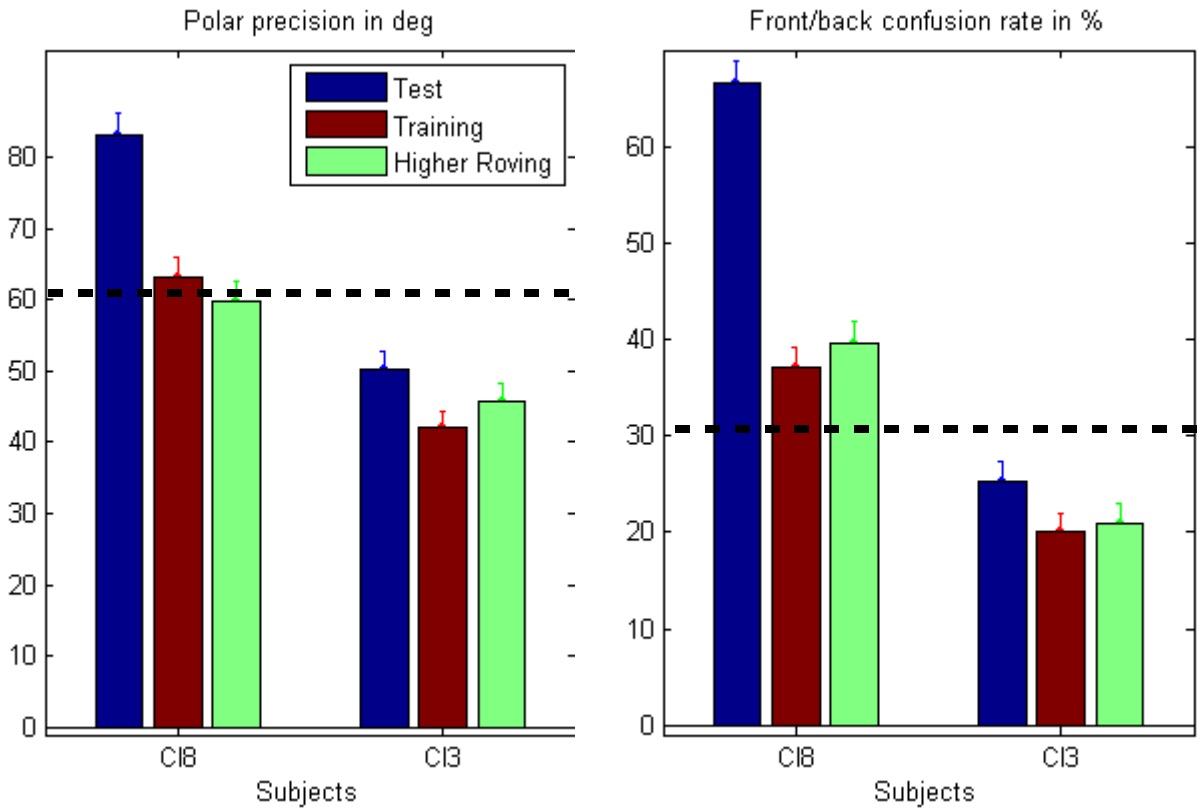
Polar Results – Without CI8

- Polar:
  - 3 CIs worse than NHs but **better** than chance!
  - CI8 performed at chance



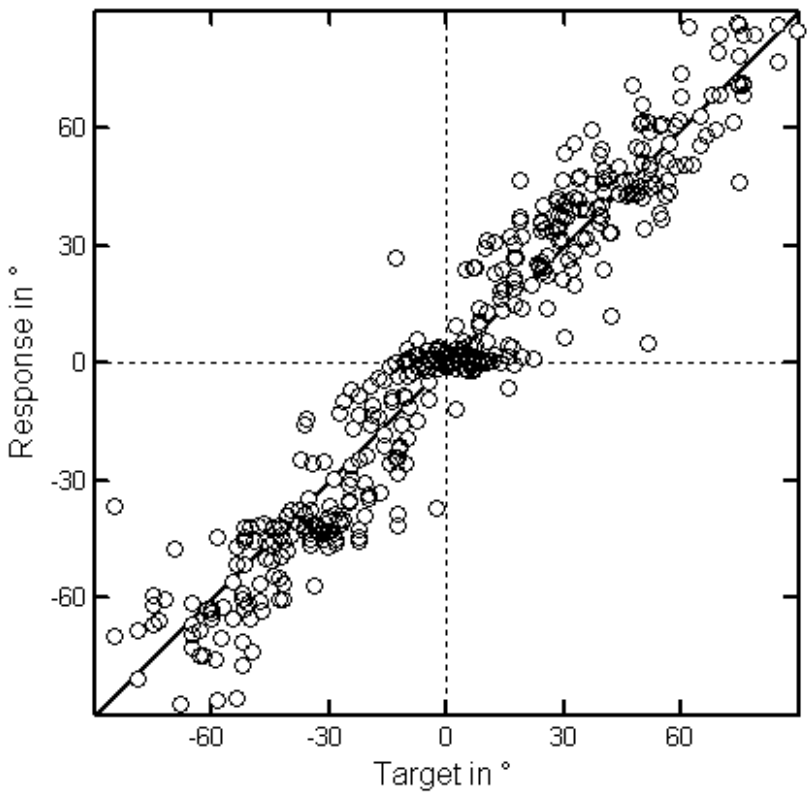
Polar Results – Effect of Roving?

- 2 subjects tested with higher roving (10 dB range)
- No systematic changes

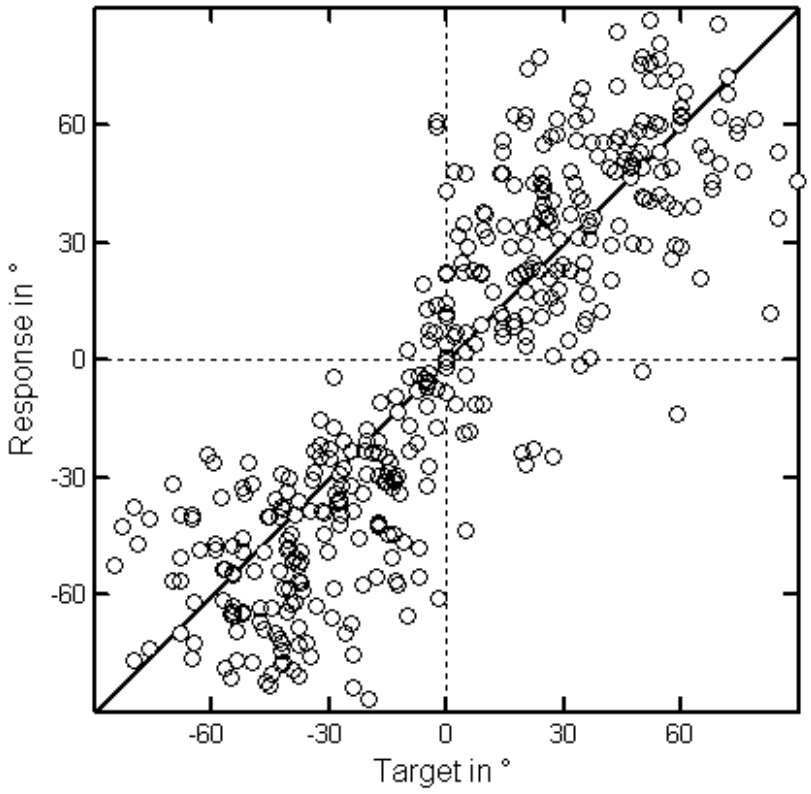


Lateral Results - Naïve Subjects

NH

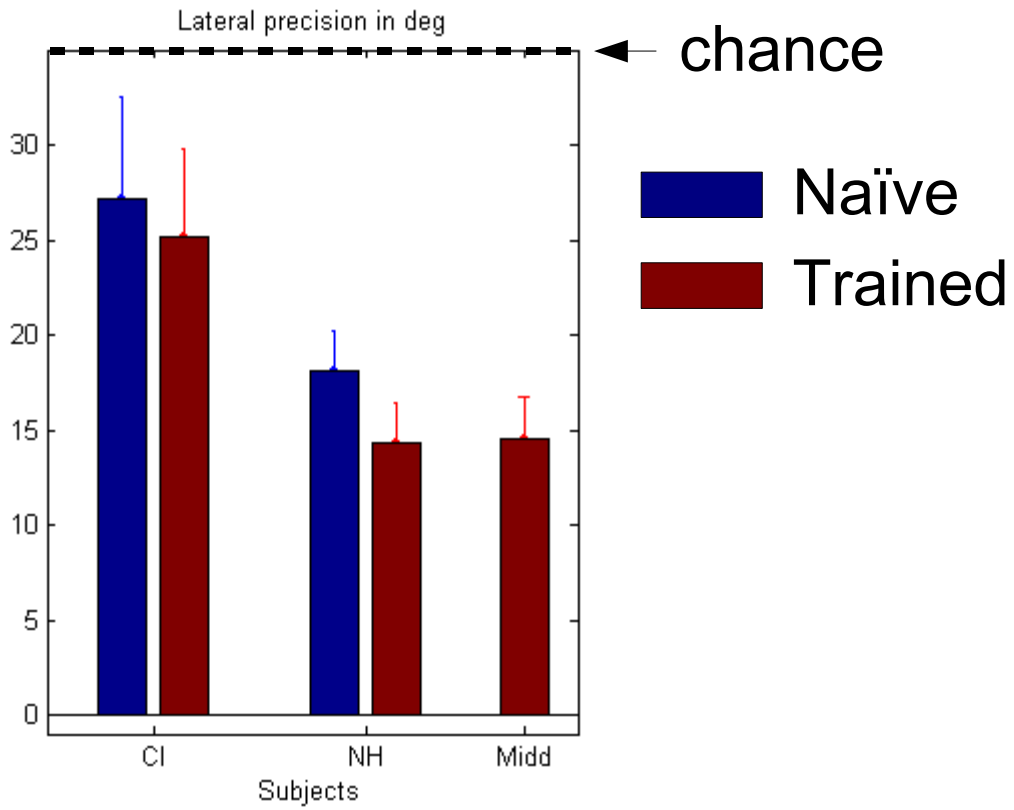


CI



Lateral Results – Group Data

- Lateral Precision:
  - CIs worse than NHs and much better than chance



Summary

- Training (300 trials) is necessary:
  - Strong training effects within first tens of trials
  - Almost no further training effects over hundreds of trials
- Lateral:
  - Precision of CI worse than NH listeners:
    - CI: 25° precision
    - NH: 15° precision
  - Already investigated by others
    - Tyler et al. (2002); van Hoesel et al. (2002); van Hoesel & Tyler (2003); Nopp et al. (2004); van Hoesel (2004); Schoen et al. (2005); Seeber et al. (2002, 2008)

Summary

- Polar:
  - One CI listener performed at chance { precision: 60° f/b confusions: 30 %
  - Three CI listeners were better than chance and worse than NH listeners:
    - CI: 43° precision, 22 % f/b confusions
    - NH: 30° precision, 12 % f/b confusions
  - At least one CI listener mainly relied on spectral cues
    - 5 dB roving range: 41° precision, 20 % f/b confusions
    - 10 dB roving range: 46° precision, 21 % f/b confusions
- Spectral cues:
  - Measurable for current CI systems
  - Perceptually usable for front/back discrimination

Outlook

- Can we do better?
  - Get more spectral cues
    - Place microphones into the ear canal
  - Improve the stimulation strategy:
    - Extend the frequency range
    - Change the frequency-to-place mapping (Goupell *et al.*, 2008)
    - Contrast spectral cues according to subjects' spectral profiling ability (Goupell *et al.* under review)